Social Media Debates, Climate Change, and Greenium

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This version: January 15, 2025

Abstract

This paper proposes a theoretical model for green asset pricing where the expected non-financial payoffs and the ex-ante uncertainty of such payoffs are incorporated into investors' utility functions. The model predicts that the degree to which green assets are priced favourably, greenium, is a time-varying concept. We find that such greenium does not monotonically increase over time as environmental awareness is enhanced. Rather, greenium decreases with respect to uncertainty over global warming and climate change issues. Our study utilises all corporate green bonds available in the Bloomberg terminal during the sample period from January 2013 to December 2022. Contributing to the literature on green bonds, we find that such bonds sell for a premium compared to non-green bonds ceteris paribus. Furthermore, increases in the measure of uncertainty derived from social media debates on global warming issues leads to statistically significant and economically meaningful reductions in greenium at issuance.

Keywords: climate change, global warming, green bonds, social media, sustainable finance, Twitter.

JEL Codes: G10, G11, G12, G40

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We are grateful for valuable suggestions and comments from Chris Adcock, Tim Loughran, and participants in ICMA research seminar, Adam Smith Sustainability 2024 Conference, FMA 2024 Annual meeting. Remaining errors are of our own.

1. Introduction

Global warming and climate change potentially impose the most severe threats and devastating consequences to human existence, according to Bloomberg (2022). Even “mild” climate change consequences, such as powerful cyclones, lead to significant negative outcomes (Calabrese et al., 2024). Tackling global warming requires a collective effort, while deep uncertainty is inherently associated with climate change and global warming (Stern et al., 2022). Increased awareness of climate change issues, proxied by the volume of climate change news (Engle et al., 2020; Ardia et al., 2022), is associated with more favourable pricing of green assets (e.g. Pastor et al., 2022). However, increased flows of such news inevitably induce fiction (e.g., Trump’s global-warming hoax, other noise on Twitter and other social media platforms), which polarizes investors’ beliefs. This paper focuses on the dispersion of beliefs in green asset pricing. Specifically, we propose a green uncertainty index derived from social media debates and examine green bond yields as an instrument for empirical testing of our model.

Social norms and public awareness regarding global warming problems could be embedded in investors’ decisions. For example, Hong and Kacperczyk (2009) show certain investors shun away from holding ‘sin stocks’ (e.g., those of tobacco, casino, and alcohol companies). The concept could also be applied inversely to environmentally responsible investors and ‘green’ assets. In this context, changes in social norms and public attitudes towards environmental issues potentially affect efforts to finance climate change remedies. Fama & French (2007) and Pastor et al. (2021) propose investors' tastes in asset pricing models. Geczy et al. (2021), Baker et al. (2022), and Pastor et al. (2022) empirically confirm that climate/green premium accounts for a large part of green asset returns compared to 'grey' / non-green assets. Huynh and Xia (2021) posit that investors hedge against climate change risks, which explains their findings of increasing demands for bonds with high climate-change news betas. If such non-monetary payoffs are incorporated in investors' calculations, both the ex-ante expected value and uncertainty of such payoffs should be embedded in their utility functions as well. This study models green asset pricing with that guidance.[1]

The model predicts that a green discount/premium, i.e., greenium (Larcker and Watts, 2020), is a time-varying concept; as such, greenium does not monotonically increase as public awareness of environmental issues enhances, as one may expect. In fact, greenium decreases with respect to uncertainty about global warming and climate change issues. We propose a green uncertainty index derived from social media debates on climate change-related issues.

Green bonds are fixed-income securities, the proceeds of which are used to finance environmental or climate-related projects. This marks the fundamental difference between green bonds and conventional debt instruments. Since the first issuance of the Climate Awareness Bond in 2007 by the European Investment Bank, the green bond market has been growing rapidly, with a wide range of issuers, including supranational, corporates, sovereigns, and municipalities in over 53 different currencies across 96 countries. In year-end 2023, the total outstanding value of green bonds is 2.8 trillion U.S. dollars, about 1% of global debts. Whether or not green bonds significantly contribute to the financial market and sustainable investment depends, to a certain extent, on how those debt instruments are priced in the market. Our paper focuses on this critical topic.

We choose green bonds for our empirical investigation for several reasons. Most notably, signals from bond yields at issuance are less noisy compared to returns of 'green' stocks. In addition, classifying green versus non-green stocks is much more prone to controversies than green versus non-green bonds.

The pricing of green bonds has been touched upon in several research papers, but there has been no consensus regarding how green factors should be incorporated nor whether green premium exists. Comparing the yield at issuance between green bonds and non-green bonds,

[1] Alternatively, investors could implicitly apply a discount on non-monetary payoffs with high ex ante uncertainty. This approach is logically indistinctive to our modelling of investors' utility functions.

the works by HSBC (2016) and the Climate Bond Initiative (2017) find no significant difference in the yield of those two types in the primary bond market. Other analyses conducted by ICE (2016) and OECD (2017b) confirm the above findings, suggesting that there is no willingness to pay a premium for acquiring green bonds. In the secondary market, Hachenberg and Schiereck (2018) find no evidence of a significant difference in yield between green bonds and their conventional counterparts. Supporting this finding, Larcker and Watts (2020) use a sample of green municipal bonds matched with nearly identical securities issued for non-green purposes by the same issuer on the same day and find that no difference in pricing for both issues exist. Using a sample period 2013 to 2018, Flammer (2021) confirms that there is no significant difference between yields of green and non-green corporate bonds. In contrast, other studies find that a "green" premium attached to green bonds exists, i.e., green bonds exhibit lower yields than non-green ones (Ehlers and Packer, 2017). Zerbib (2019) uses a matching procedure to match green bonds with conventional bonds and finds a statistically significant small green bond premium. After considering taxation, Baker et al. (2022) find that green municipal bonds are issued at a premium of about five to seven basis points compared to otherwise similar bonds on the primary market.

It has been mentioned that non-pecuniary motives, especially pro-environmental preferences and a sense of being socially responsible, may well be factors explaining investors' willingness to give up financial benefits to invest in environmentally friendly or socially responsible assets (Baker et al., 2022). A similar argument is found in Fama and French (2007), which shows that investors' tastes for a certain type of asset enter into the investors' utility functions and lead to modifications in equilibrium price. Socially responsible investing is one leading example of taste in their model. Supporting this finding, Geczy et al. (2021) show that socially responsible investing costs vary from a few basis points up to 30 basis points per month, depending on investors' beliefs on asset pricing models. Avramov et al. (2022) find that ESG rating discrepancies between raters affects stocks' returns. Ardia et al. (2023) show a correlation between climate change concerns and the degree to which green stocks outperform brown stocks (i.e., non-green stocks).

Consistent with prior papers (Baker et al., 2022), our empirical results find that green bonds are priced at a premium. Corporate green bonds' yield-to-maturity at issuance is lower than those for non-green bonds after controlling for key determinants of bond yields; namely, average credit ratings from Fitch, Moody's, S&P's, maturity, bond size, macro-economic factors, and a set of issuer's industry, market issued and year fixed effects. Different to prior papers, we document a significant linkage between social media debates and green bond pricing. Specifically, we show, both theoretically and empirically, that ex-ante uncertainty from social media debates is incorporated into investors' learning processes. We employ social media debates around global warming topics and all green bonds from the Bloomberg terminal from 1 January 2013 to 31 December 2022. Specifically, all tweets[2] containing both keywords related to global warming issues and words of uncertainty in Loughran and McDonald (2011)[3] are collected. Following the method of Baker et al. (2021), we construct an (normalised) index for measures of uncertainty derived from such tweets posted during a period of one month prior to bond issuance. The empirical investigations find that increases in the measure of uncertainty lead to significantly large decreases in greenium. Overall, the findings are in strong support of the model's conjectures.

We contribute to a few different strands of literature. First, the ex-ante uncertainty of non-monetary payoffs–e.g., pro-environmental payoffs and high ESG stocks–should be incorporated into asset pricing models (Fama and French, 2007; Hong and Kacperczyk, 2009; Pastor et al., 2021). Particularly, global warming and climate change are distant-future contingent processes that involve "deep" uncertainty (Stern et al., 2022). Increased flows of

[2] We use the Twitter API to collect about 7 million Twitter posts on global warming and climate change. We clean these tweets following prior papers e.g. removing non-English tweets or tweets containing only links or URLs, removing special characters, such as 'http', 'https', and 'www', hashtag, and user identifier tokens.

[3] We augment the list of uncertainty words in Loughran and McDonald (2011) by (i) excluding words associated with risks such as "deviation", "exposure", "fluctuation", "volatility" etc.; (ii) adding some words frequently mentioned in tweets on this topic such as "fantasy", "fabulous", "fake", "hoax", "myth", "wonderful" etc.

climate change news, as awareness of such issues enhances, also generates anti-climate fictions, especially spread in social media platforms which exaggerate 'echo chamber' and self-selection-bias issues (Cookson et al., 2023). These, in turn, polarize investors' beliefs and increase ex-ante uncertainty. Our paper also supplements research on how (mis)information / biases propagate via social networks (Hirshleifer, 2020). Investors are often connected and boundedly rational. Full-batch transmission bias usually happens as some people are "credulous". Secondly, we contribute to the debate on pricing of green bonds. Our proposal on the time-varying greenium explains the greenium puzzle where contrast results documented in prior papers (e.g. Zerbib, 2019; Larcker and Watts, 2020; Flammer, 2021; Baker et al., 2022). In addition, there are practical implications for investment managers and corporate and policy decision-makers, such as the polarization of opinions on important issues such as global warming and climate change. Green bond issuers would benefit from timing the market for more favourable green uncertainty.

The remainder of this paper is organized as follows. Section 2 proposes an intuitive theoretical framework for green asset pricing and testable hypotheses. Section 3 describes the data and regression equations for the empirical investigations. Section 4 presents the empirical results. Section 5 summarizes the findings and conclusions.

2. Model and Hypothesis

We study an overlapping generations model with two-period-lived agents. There are 2 assets in the economy: (i) a risk-free asset with a perfectly elastic supply, and (ii) a risky green asset with a finite supply (normalized at one unit).[4]

The price of the risky asset fluctuates over time, while the price of the risk-free asset is fixed (normalized at one unit). All assets pay the same amount (r) in dividends. Therefore, r

[4] The risky asset represents all risky assets in the economy, where some of them do (don't) have green elements. Alternatively, we can include 2 risky green and non-green assets. This setup does not change any main findings in our model.

denotes the risk-free rate, while there is ex-ante uncertainty on the dividend yield of the risky asset ($\frac{r}{P_t}$), where P_t is the price of the risky asset.

There is a finite set of rational investors in the economy. Investors have a constant absolute risk aversion (CARA) utility function of wealth:

$$U = a - (1 - g_i)e^{-2\gamma w_i} \tag{1}$$

where $2\gamma = \frac{-U''}{U'}$ is the coefficient of risk tolerance;

w_i is the investor's wealth;

g_i is the coefficient of how much investor i is willing to trade monetary for non-monetary (e.g., environmental) payoffs $g_i \in [0,1]$; and $i \in \{1,2,..,N\}$. w_i and g_i are independent.

The coefficient g_i depends on investor *i*'s perception on a range of issues, including the urgency of the global warming phenomenon, how devastating the consequences would be if global warming were left unchecked, and how these consequences would be translated to his/her own penalties. In addition, confronting global warming requires a collective effort. Communication plays an important role for opinion formations (DeMarzo et al., 2003; Hirshleifer, 2020). It is reasonable to assume that investor *i* receives influences from his/her social network in estimating parameter g_i.

Investors communicate and learn about global warming issues before making decisions. An investor *i* interacts with m agents in the social network on the topic of global warming consequences and the benefits of funding remedial efforts (e.g., green assets). After one round of communication, the investor's belief post-communication is expressed by the following equation.

$$g_1^i = \sum_{j=1}^{m} \theta_{ij}\, g_0^j \tag{2}$$

where θ_{ij} is a psychological measure of how much agent *i* believes in agent *j*. It is noteworthy that agent *i* might not interact with all agents in the network. θ_{ij} can take zero if either s/he did not listen or does not trust signals from certain agents. Therefore, θ_{ij} subsumes the listening structure and weightings in the learning process of agent *i* (DeMarzo et al., 2003).

$$\theta_{ij} \in [0,1)$$

$$\sum \theta_{ij} = 1$$

$$g_0^j \geq 0$$

The updating rule (2) can be rewritten in vector notation, as follows:

$$G_t^1 = \Theta G_t^0 \tag{3}$$

where G_t^1 (G_t^0) is the vector of agents' beliefs post- (prior-) communication.

Θ is the listening matrix.

Following prior papers, we assume that agents are bounded-rational; i.e., they are not able to distinguish new and repeat information. The presence of green benefits post-communication is essentially determined by how frequently the green benefits are repeated during communication.

The investors' beliefs after *n* rounds of communication becomes:

$$G_t = \left[\prod_{s=1}^{n} \Theta_s\right] G_0 \tag{4}$$

Proposition 1.

If investors assign the same weights θ_{ij} for all those sharing similar beliefs and a zero weight for all those with opposite beliefs, communication will stratify investors' beliefs:

$$\lim_{n \to \infty} G_t = G_\infty \tag{5}$$

where G_∞ contains zeros and a positive number for every other element.[5] Here we can see that communication alters investors' beliefs about green benefits. All investors who initially share certain beliefs about green benefits (i.e., $g_i > 0$) will reach a consensus, while other investors' g_i remains at zero.

We can illustrate the process from Equations (3)-(5) in the following example:

Initial beliefs:

$$G_0 = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \\ 0.5 \end{bmatrix}$$

Initial listening matrix:

$$\Theta_0 = \begin{bmatrix} 0.5 & 0 & 0.5 & 0 & 0 \\ 0 & 0.5 & 0 & 0.3 & 0.2 \\ 0.4 & 0 & 0.6 & 0 & 0 \\ 0 & 0.3 & 0 & 0.5 & 0.2 \\ 0 & 0.3 & 0 & 0.2 & 0.5 \end{bmatrix}$$

After one round of communication:

$$G_1 = \begin{bmatrix} 0.5 & 0 & 0.5 & 0 & 0 \\ 0 & 0.5 & 0 & 0.3 & 0.2 \\ 0.4 & 0 & 0.6 & 0 & 0 \\ 0 & 0.3 & 0 & 0.5 & 0.2 \\ 0 & 0.3 & 0 & 0.2 & 0.5 \end{bmatrix} \times \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \\ 0.5 \end{bmatrix} = \begin{bmatrix} 0 \\ 0.9 \\ 0 \\ 0.9 \\ 0.75 \end{bmatrix}$$

After $n=100$ rounds of communication:

[5] The proof for this proposition is in Appendix A.

$$G_n = \begin{bmatrix} 0.444 & 0 & 0.555 & 0 & 0 \\ 0 & 0.375 & 0 & 0.339 & 0.285 \\ 0.444 & 0 & 0.555 & 0 & 0 \\ 0 & 0.375 & 0 & 0.339 & 0.285 \\ 0 & 0.375 & 0 & 0.339 & 0.285 \end{bmatrix} \times \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \\ 0.5 \end{bmatrix} = \begin{bmatrix} 0 \\ 0.857 \\ 0 \\ 0.857 \\ 0.857 \end{bmatrix}$$

Via debates and interactions, investors who initially don't include green benefits in their utility functions always end up with a zero estimation of green benefits: $g_i = 0$. On the other hand, all other investors' estimations converge on a common value, which depends on the mass of initial estimations of the green benefits in the whole social network. Investors are now clustered into Group A and Group B.

Group A: Investors who are aware of the consequences associated with climate change and global warming. We term these as believers in the global warming phenomenon. They know that global warming would likely impose end-game impacts in period $t+1$; e.g., their retirements. They are willing to scarify certain financial gains for funding global warming remedies; hence, their estimation includes gaining extra satisfaction from holding green assets: $g_A \in (0,1)$.

Group B: Investors who either do not believe or are not aware of such consequences; hence, they do not appreciate efforts in combating global warming and climate change. We term these as non-believers in the global warming phenomenon. Their utilities do not include a similar green benefit: $g_B = 0$.

It is noteworthy that both investor groups are rational and that the extra utility for investing responsibly is driven by their own self-interests. The total mass of investors in both groups is normalised at one:

$$\mu_A + \mu_B = 1 \tag{6}$$

where μ_i denotes the mass of Group $i \in \{A, B\}$.

The maximisation of Group B investors' expected utility function is equivalent to maximise the standard function, as follows:

$$\overline{w} - \gamma\sigma_w^2 \tag{7}$$

where $\overline{w}$ is the expected final wealth, while σ_w^2 is one period ahead of the variance of wealth.

Group A investors maximise a function, which includes both the expected final wealth and the expected green benefits, as well as their variances:

$$\overline{w} + \overline{G} - \gamma\sigma_w^2 - \sigma_G^2 \tag{8}$$

where $G = -\ln(1 - g_A)$, while $\overline{G}$ is the expected green benefits, and σ_G^2 is one period ahead of the variance of the green benefits.

Therefore, Group A demands amount D_t^A of the green asset to maximize the following:

$$D_t^A[r + E_t(P_{t+1}) - (1 + r)P_t + E_t(G_{t+1})] - \gamma\left(D_t^A\right)^2 E_t\left(\sigma_{P,t+1}^2\right) - \left(D_t^A\right)^2 E_t\left(\sigma_{G,t+1}^2\right) \tag{9}$$

Solving Equation (9) gives the demand of the green asset from Group A of investors:

$$D_t^A = \frac{r + E_t(P_{t+1}) - (1 + r)P_t + E_t(G_{t+1})}{2\gamma E_t\left(\sigma_{P,t+1}^2\right) + E_t\left(\sigma_{G,t+1}^2\right)} \tag{10}$$

Applying a similar maximization procedure for Group B of investors, we show the demand of the green asset, as follows:

$$D_t^B = \frac{r + E_t(P_{t+1}) - (1 + r)P_t}{2\gamma E_t\left(\sigma_{P,t+1}^2\right)} \tag{11}$$

The differences between Equation (10) and Equation (11) are the expected green benefits of investing sustainably $E_t(G_{t+1})$ and ex ante uncertainty about the green benefits $E_t\left(\sigma_{G,t+1}^2\right)$. Notably, the demand of the green asset from a Group A investor, who prefers investing sustainably, is larger than that of a Group B investor, if the ratio between the expected green benefits over the expected variance of the green benefits exceeds a threshold which relates to the ratio between the expected return over the expected variance of the asset prices.

$$\frac{E_t(G_{t+1})}{E_t(\sigma^2_{G,t+1})} > \frac{r + E_t(P_{t+1}) - (1+r)P_t}{2\gamma E_t(\sigma^2_{P,t+1})}$$

Imposing the market clearing condition, the equilibrium price needs to satisfy:

$$\mu_A D_t^A + \mu_B D_t^B = 1 \tag{12}$$

The price of the green asset at equilibrium is:

$$\begin{aligned} P_t = \frac{1}{1+r}\Bigg[& r + E_t(P_{t+1}) - 2\gamma V_{P,t} + \left(1 + \mu_A \frac{2\gamma V_{P,t}}{2\gamma V_{P,t} + \mu_B V_{G,t}}\right) E_t(G_{t+1}) \\ & - \mu_A \frac{2\gamma V_{P,t} V_{G,t}}{2\gamma V_{P,t} + \mu_B V_{G,t}}\Bigg] \end{aligned} \tag{13}$$

where

$$V_{P,t} = E_t(\sigma^2_{P,t+1})$$

$$V_{G,t} = E_t(\sigma^2_{G,t+1})$$

The equilibrium price of the green asset does not only depend on the expected financial fundamentals of the asset but also on the expected values of the green benefits; i.e., both the mean and ex ante variance, and the proportion of environmentally responsible investors in the economy.

Applying a restriction that the unconditional distribution of P_t is identical to that of P_{t+1}, Equation (13) can be solved recursively as:

$$P_t = 1 - \frac{2\gamma V_{P,t}}{r} + \left(1 + \mu_A \frac{2\gamma V_{P,t}}{2\gamma V_{P,t} + \mu_B V_{G,t}}\right)\frac{E_t(G_{t+1})}{r} - \frac{\mu_A}{r}\frac{2\gamma V_{P,t} V_{G,t}}{2\gamma V_{P,t} + \mu_B V_{G,t}} \tag{14}$$

The price of the green asset depends on its (discounted future cashflows) fundamentals (normalized at one), normal risk-premium, and the impact of environmentally responsible investors. This impact could either be positive or negative for the pricing of the green asset. On one hand, the expected benefit of investing responsibly $\frac{E_t(G_{t+1})}{r}$ increases the price. On the other hand, uncertainty about the green benefit of investing responsibly $V_{G,t} = E_t(\sigma^2_{G,t+1})$ depresses the price. This is a quite intuitive implication, since the benefits of investing in global warming require a collective effort. Uncertainty regarding how much holding green assets can be converted to actual remedies for global warming reduces Group A investors' appetites.

The price of the green asset deviates from its fundamental value. The difference between the price and the fundamental, we term greenium, could be either positive or negative, depending on both the expected green benefits and the ex-ante variance of such benefits.

For empirical investigations, we cannot measure the expected green benefits. Moreover, following prior papers (DeMarzo et al., 2003), we argue that the expected value of investors' beliefs stays relatively stable via social network communication, while the variance of their beliefs changes significantly with each round of communication. Therefore, we focus on the implication of the variance $V_{G,t}$:

$$\frac{\partial P}{\partial V_G} = -\frac{2\mu_A \gamma V_P}{r} \times \frac{2\gamma V_P + \mu_B E_t(G_{t+1})}{\left(2\gamma V_P + \mu_B V_{G,t}\right)^2} \qquad (15)$$

Equation (15) implies Hypothesis 1, that the price of the green asset decreases with respect to ex ante uncertainty about green benefits.

In addition, Equation (14) gives us a direct measure for greenium, as follows:

$$\phi_t = \frac{E_t(G_{t+1})}{r} + \frac{2\gamma \mu_A V_{P,t}}{2\gamma V_{P,t} + \mu_B V_{G,t}} \frac{E_t(G_{t+1}) - V_{G,t}}{r} \qquad (16)$$

Equation (16) implies Hypothesis 2, that greenium is positive when the expected green benefits are larger than the ex-ante uncertainty on such an issue.

The first derivative of the greenium, with respect to ex ante uncertainty on green issues, is also negative:

$$\frac{\partial\phi}{\partial V_G} = -\frac{2\mu_A\gamma V_P}{r} \times \frac{2\gamma V_P + \mu_B E_t(G_{t+1})}{\left(2\gamma V_P + \mu_B V_{G,t}\right)^2} \tag{17}$$

Equation (17) implies Hypothesis 3, that greenium decreases with respect to ex ante uncertainty on such green issue.

3. Data and Empirical Strategy

Empirical investigations rely on data from two sources: (i) the primary market of corporate green bonds; and (ii) social media communication.

First, we select green bonds over stocks of companies with green credentials due to a number of reasons. Signals from bond yields at issuance are less prone to noise after controlling for major determinants, such as credit ratings, maturities, and liquidity. In addition, examining bond yield differences between green versus non-green bonds presents clearer-cut evidence than return differences between environmentally friendly vs less environmentally friendly stocks. Finally, distinguishing between environmentally friendly vs less environmentally friendly stocks is subject to controversy, since data on companies' environmental impact remains limited despite recent developments (e.g., climate disclosures).

We collect data from corporate green bonds from Bloomberg from 1 January 2013 to 31 December 2022. The sample includes 4,287 corporate green bonds. In addition, we collect over 30,000 ordinary (non-green) bonds for matching green bonds to test Hypotheses 2 and 3. Following prior papers, we conduct a cleaning procedure. First, we only keep bonds issued in major currencies (i.e., U.S. Dollar, Euro, British Pound, Swiss Franc, Canadian Dollar, Australian Dollar, and Japanese Yen). This cleaning criteria leaves us with 2,761 bonds. Among non-major currency-denominated green bonds, those in the Chinese Yuan account for the highest number, 937. Second, we drop all bonds that do not have plain vanilla fixed coupons or zero coupons. This removes 393 green bonds with other types of coupons such as floating or fixed then floating coupons. The rationale is that we investigate yield-to-maturity at bond issuance, and fixed coupon bonds present cleaner evidence as investors in these bonds would not require other contingent inputs such as future interest rate regimes. We also drop all (101) bonds without credit ratings from Fitch, Moody's, and S&P's. Eventually, 2267 green bonds and 25,026 non-green bonds remain. Investigating yield-to-maturity at issuance also presents another advantage for our paper compared to secondary markets, as they are sampled at lower frequencies, which allows higher rounds of communication and interaction between investors.

We use the Twitter API to collect all Twitter posts containing both (i) global warming keywords (e.g., climate change, global warming); and (ii) any word in the set of words of uncertainty (e.g., apparently, appear, arbitrarily, confusing, depend, doubtful, magically, presumably, probably, randomly, speculate). We augment the list of words of uncertainty in Loughran and McDonald (2011). Specifically, we exclude words implying risks such as "deviate", "deviation", "exposure", "fluctuation", "risky", "uncertainty", "variation", and "volatility". The rationale is to avoid capturing the impact of climate change risks on asset pricing, which have been investigated in prior papers (Engle et al., 2020, Huynh and Xia, 2021). Additionally, we add "fantasy", "fantastic", "fabulous", "fake", "fraud", "fraudulence", "hoax", "myth", and "wonderful". Eventually, 189 words make up the set of uncertainty keywords.

For each tweet, we extract the tweet content, the time posed of the tweet, the name of the user, the number of likes, and the number of retweets. Following prior papers, we drop all non-English tweets. Additionally, special characters are deleted from tweet messages, such as link tokens (e.g., 'http', 'https', and 'www'), hashtag tokens (e.g., '#'), and user identifier tokens (e.g., '@'). All tweets containing only links or URLs are dropped. We end up with a database of 6,823,707 tweets during the sample period 1 January 2013 to 31 December 2022. We calculate the measure of uncertainty from social media debates on global warming based on the number of tweets accumulated during a month prior to each date[6]. Following Baker et al. (2021), we normalise the measure of uncertainty to a mean of 100.

Table 1 presents the descriptive statistics of green vs non-green bond characteristics issued during the sampling period. The average yield-to-maturity of green (non-green) bonds is 2.3% (3.49%) implying a significant difference between the two types of bonds. Notably, standard deviation of yields from green bonds is also larger than that of non-green bonds, implying high volatile yields from green bonds comparative to non-green bonds.

Our empirical investigations are based entirely on the hypothesis that (certain) investors prefer green bonds to ordinary bonds ceteris paribus. The first empirical equation is as follows:

$$y_i = \alpha + \beta \mathrm{Green}_i + \gamma C_i + \epsilon_i \tag{18}$$

where y_i is bond yield-to-maturity at issuance.

Green_i is a dummy variable for green bond status.

C_i is a vector of control variables, including bond characteristics, macro-economic variables, and a set of year effects, issuer's industry effects and issued market effects. The bond characteristics include (log) bond size; number of years to maturity; average credit ratings from Fitch, Moody's, S&P's; and the interaction term between average credit rating and maturity. The macro-economic variables include policy interest and inflation rates.

For hypothesis 1, we estimate:

$$y_{t,i} = \alpha + \beta \mathrm{Uncertainty}_t + \gamma C_{i,t} + \epsilon_{i,t} \tag{19}$$

where $y_{t,i}$ is green-bond yield-to-maturity at issuance.

$\mathrm{Uncertainty}_t$ is the measure of uncertainty from social media debates on global warming and climate change.

$C_{i,t}$ is a vector of control variables including bond characteristics, macro-economic variables, and a set of year effects, issuer's industry effects and issued market effects. The bond

[6] We consider 1-week and 10-week periods, which yield quantitatively similar results.

characteristics include (log) bond size; number of years to maturity; average credit ratings from Fitch, Moody's, S&P's; and the interaction term between average credit rating and maturity. The macro-economic variables include policy interest and inflation rates.

For Hypothesis 2, we conduct an event study of green bonds' yield-to-maturity and greenium at issuance. Greenium is the difference in yield-to-maturity between a green bond and matched non-green bonds. We use 5 matching criteria as follows: (i) similar credit worthiness (i.e., less than 2-notch difference from average ratings by Fitch, Moody's, S&P's); (ii) similar maturity (i.e., a maximum of 2 years difference in numbers of years to maturity); (iii) issued within one month; (iv) both green and non-green bonds issued in the same currency; and (v) issuers of non-green bonds are in the same industry as green bond issuers. We test for any significance in the green bonds' yield-to-maturity and/or greenium issued during high (low) versus a normal measure of uncertainty from social media debates on global warming and climate change. We define high (low) uncertainty period if the social media measure of uncertainty is higher (lower) than the 3rd (1st) quartile from its distribution.

For Hypothesis 3, we estimate:

$$g_{t,i} = \alpha + \beta \mathrm{Uncertainty}_t + \gamma C_{i,t} + \epsilon_{i,t} \tag{20}$$

where $g_{t,i}$ is greenium of bond *i* at issuance.

This is the yield-to-maturity difference between matched non-green and green bonds. A matched non-green bond satisfies criteria as follows: (i) similar creditworthiness with the corresponding green bond; (ii) similar maturity with the corresponding green bond; (iii) the non-green bond is issued within one month around the issuance of the corresponding green bond; (iv) both green and non-green bonds issued in the same currency; and (v) issuers of non-green bonds are in the same industry as green bond issuers.

$\mathrm{Uncertainty}_t$ is the measure of uncertainty from social media debates on global warming and climate change.

$C_{i,t}$ is a vector of control variables as in Equation (19).

4. Empirical Results

Does Greenium exist? Is there evidence of interaction with the Green Uncertainty Index?

Table 2 reports regression results for Equation (18). The dependent variable is bond yield-to-maturity at issuance. The key independent variable is a green status dummy. In Column (2), we add bond characteristics and macroeconomic factors as control variables. Bond characteristics include logarithm of bond size; maturity; and average credit ratings from Fitch, Moody's, and S&P's. Macroeconomic factors are inflation and policy interest rates. In Column (3), we also include the interaction term between average rating and maturity. In the final column of the table, Column (4), we add a set of dummy variables representing the issued market, issued year, and industry of the bond issuer. In all specifications, we find a strongly significant and negative coefficient of the green status dummy. In line with Baker et al. (2022), our results show that green bonds sell for a significant premium. The magnitude of this effect (about 23-31 basis points) is economically meaningful given the mean yield to maturity is 3.49% (Table 1). This magnitude is much higher than what was documented in Baker et al. (2022), who investigate municipal bonds with usually much lower yields. In addition, the green bond dummy coefficient is more than a third of that for the credit rating, thus implying that green bonds are priced as if they were a third of a notch more highly rated. The empirical results support our assumption for the theoretical model, that certain investors significantly favour green over non-green bonds ceteris paribus.

Next, we investigate whether this favour of green bonds interacts with our measure of ex-ante uncertainty on social media. Specifically, we add an interaction term between the high green uncertainty dummy and the green bond dummy on the right-hand side of Equation (18). Table 3 presents regression results for this exercise. The coefficient of the interaction term is highly significant and positive. Green bonds issued during periods of the high green uncertainty index are, on average, charged significantly more. The magnitude of this coefficient is about one-fifth of the green status dummy. Notably, most of the high values in our measure of uncertainty fall in the 2019-2020 and post-2021 periods, as seen in Figure 1, which coincides with Trump's presidential re-election campaign and the rise of populism. There are multiple instances where green bond issuers pay significantly higher yields during high-uncertainty periods.[7, 8]

Table 4 reports regression results for Equation (19). The dependent variable is the green bond yield-to-maturity at issuance. The key independent variable is the measure of uncertainty derived from social media debates. Similar to Tables 2 and 3, we control for bond size, maturity, credit rating, policy interest and inflation rates, issuer's industry, and market-issued and year-fixed effects. Notably, these estimations are run only for the sample of green bonds. In all specifications, the coefficient of our measure of uncertainty is significantly positive. This means that green bond yields vary with respect to the measure of uncertainty. Recall that the measure of uncertainty is derived from social media debates during the 1-month period prior to the issue date of the green bond. Moreover, the social media debates are typically not directly related to any green bond but to general discussions on global warming. Therefore, our investigations have a very limited possibility of endogeneity. In the most conservative specification, the estimation shows that a unit increase in the measure of uncertainty leads to about a 4-bps increases in green bond yields. During the sample period, there are large fluctuations in the measure with changes of multiple units. The magnitude of the measure of uncertainty effect on green bonds is economically meaningful. For example, green bonds would be issued at about 220 basis points higher for the period of September–October 2019 or August 2022, when the measure of uncertainty jumped 20 units. Of course, this example is

[7] Tesla and its subsidiaries issued many green bonds during the sampled period. We conduct robustness checks by dropping such bonds. The empirical results remain qualitatively the same (reported in Appendix B6).

[8] We construct our "green" uncertainty index using only English-language Tweets. One may argue that the index should have limited impacts on greenium in non-English speaking countries. Our empirical results are robust without bonds issued in non-English speaking countries' currencies i.e. Euro, Swiss Franc, Japanese Yen. These empirical results are reported in Appendices B7-B8. In addition, English is a lingua franca on social media platforms where translated posts also could be obtained with ease.

after controlling for other factors, including bond characteristics and macro-economic variables. These are in support of Hypothesis 1, in which prices of green assets decrease with respect to ex ante uncertainty about green benefits.

Table 5 reports the event study in testing Hypothesis 2. As our model predicts, the degree to which investors price green bonds favourably, greenium, is time varying. Panel A of Table 5 shows that investors require higher yields from green bond issuers during high-green uncertainty, compared to normal periods. The difference, on average, is about 71 bps. The effects of green uncertainty are asymmetric (see Panels A and B of Table 5). During the high uncertainty index periods, investors demand significantly higher yield-to-maturity from green bond issuances, but no significant difference was found during the low uncertainty regime. The differences in yields in Panels A and B may be due to time effects. However, we match a green bond to non-green bonds of similar characteristics issued within the same month in Panels C and D of Table 5. Notably, greenium is negative (positive) during periods of high (low) green uncertainty. In the presence of high uncertainty, greenium can even be negative. Investors charge green bond issuers more than non-green bond issuers ceteris paribus. We match non-green bonds to a green bond with strict criteria including similar creditworthiness, maturity, same issued currency, same industry, and issued within the same month. The result is direct evidence in support of our model, which explains that greenium varies with respect to the ex-ante uncertainty of green benefits among pro-environmental investors.

How influential are consistent social media debates?

In this section, we consider how long information on social media remains relevant for the measure of uncertainty estimation. Table 6 repeats most conservative specifications for different periods for collecting social media debates. Column (1) presents the estimation results for the 1-week period before the green bond issue date. Columns (2)-(3) report the results for 1-month and 10-week periods, respectively. In all columns, the coefficient of the measure of uncertainty is highly significant and positive. This strengthens the previous findings in support of Hypothesis 1. Regardless of the period for collecting debates on global warming and climate change, the uncertainty on such issues proves consistent and robust in affecting the pricing of green bonds.

Matching green bonds to ordinary bonds of similar quality

In this section, we match green and non-green bonds to estimate the difference in their yield-to-maturity at issuance. Each green bond is matched with non-green bonds that satisfy all of the following criteria. First, the non-green bonds should have similar creditworthiness. Specifically, the absolute difference between green vs non-green bonds' average credit ratings by Fitch, Moody's, and S&P's is less than two notches. Secondly, the difference between their maturity is less than 2 years. Third, non-green bonds are issued within one month around the issuance of the corresponding green bond. The fourth criteria are that they are issued in the same currencies. The final criteria are the same industry sort code. To test Hypothesis 3, the difference between non-green vs green bonds' yield-to-maturity at issuance is calculated. This difference is, then, employed in the estimation of Equation (20). This exercise mitigates potential omitted-variable issues, including the yield difference between bonds issued around the same time period, the same creditworthiness and maturity, and, alongside the year, issuer fixed effects should absorb business cycle issues.

In all specifications, the coefficient of the measure of uncertainty derived from social media debates is strongly significant and negative. This suggests that an increase in the measure of uncertainty leads to a decrease in greenium. In other words, the more the measure of uncertainty is, the less differently investors price green vs non-green bonds. The magnitude of the effects is about 11-14 bps, which is highly economically meaningful, considering that green bonds are, on average, issued at 2.22% (see Table 1).[9]

Social media and traditional media put in tandem

Traditional media play a significant role in attracting investors' attention on the issue of climate change. Ardia et al. (2023) introduce an index of climate change concerns derived from traditional US news outlets. They show a strong correlation between the index and the degree to which green stocks outperform brown stocks. To control for such information in the traditional news media, we include this index in our estimations of Equations (19) and (20).[10]

Table 8 presents regression estimations, including climate concerns from traditional news outlets as an extra independent variable. The coefficient of the interaction between high uncertainty and the green bond dummy is highly significant and positive, consistent with our results in Table 3. The only significant difference is that the results become moderately stronger supporting our hypothesis. Green bonds issued during periods of high green uncertainty are, on average, charged significantly more after controlling for climate change concerns or awareness of traditional news outlets.

In Table 9, we repeat the most conservative specification from Equation (19) using the climate change concerns index as an extra independent variable. Column (1) presents the results of that estimation for the 1-week period prior to the green bond issue date. Columns (2) – (3) report the results for 1-month and 10-week periods, respectively. In all columns, the coefficient of the measure of uncertainty is highly significant and positive. Regardless of the periods for collecting debates on global warming and climate change, the uncertainty surrounding such issues consistently affects green bond pricing.

[9] Results are robust for stricter matching criteria (reported in Appendices B1-B2). We match a green-bond to non-green bonds with (i) the same creditworthiness; (ii) the same maturity; (iii) issued within a month; (iv) the same issued currency; and (v) the same industry short code.

[10] Further estimations with Ardia et al (2023) index are reported in Appendices B3-B5. They are qualitatively similar to the tables in this main text.

5. Conclusion

The pressing necessity of global warming and climate change remedies requires a vast collective effort. However, many aspects of the climate change phenomenon inherently involve deep uncertainty (e.g. Stern et al., 2022). Green assets like green bonds are at the forefront of financing climate change combats. This paper proposes a simple theoretical framework where some investors are willing to sacrifice financial gains for the expected sustainable utility. The model yields several predictions. Notably, the degree to which green assets are priced favourably, greenium, is a time-varying concept. We find that such greenium does not increase over time automatically when investors become more environmentally friendly. It decreases with respect to uncertainty over global warming/climate change issues. This study complements prior literature on climate finance, focusing on how investors measure and manage climate risks.

Asset pricing literature shows that investors incorporate non-financial payoffs (e.g., tastes, social-norms, and pro-environmental preferences) in their investment decisions (Fama and French, 2007; Hong and Kacperczyk, 2009; Baker et al., 2022). We contribute to this strand of literature by incorporating ex ante uncertainty of such non-financial payoffs. One may argue that investors include non-financial payoffs in their investment calculations and that such payoffs are contingent. For example, pro-environmental payoffs depend greatly on future coordinated efforts and how green projects perform. Therefore, investors should account for both the expected (financial and non-financial) payoffs and the ex-ante uncertainty over such payoffs in their decisions.

Our empirical investigations are based on a sample of all green bonds available in the Bloomberg database over a 10-year period from 2013 to 2022. Consistent with recent papers, we find that green bonds sell for a premium compared to non-green bonds ceteris paribus. Importantly, we document a strong association between a lagged measure of uncertainty and green bonds' yield-to-maturity at issuance and greenium. This directly adds empirical evidence supporting the prediction of Pastor et al. (2022) regarding the association between green asset returns and environmental news. However, the channel of the association is via investors' preferences, in line with Fama and French (2007).

This study raises important implications. First, the ex-ante variance of non-monetary payoffs, such as pro-environmental payoffs and high ESG stocks, should be modelled in asset pricing. Second, there is a strong link between the ex-ante uncertainty of such payoffs and green premiums. There are practical implications for investment managers and corporate and policy decision-makers. There is an urgent need for resources to dampen the polarization, hence a variance of beliefs on important issues such as global warming and climate change. Especially, rapid increases in flows of pro-climate change news also attract unintended fiction, i.e. anti-climate-change noise. At the micro level, there are clear benefits for firms to enhance their ESG disclosures and thus reduce the ex-ante variances of their sustainable projects. Finally, our research indicates the valuable advantages of making data accessible to researchers. The extensive volume of social media data should be made accessible for analysis and research purposes. This data, in turn, plays a crucial role in detecting patterns and guidance for policymakers and practitioners concerning all aspects of social interactions and activities.

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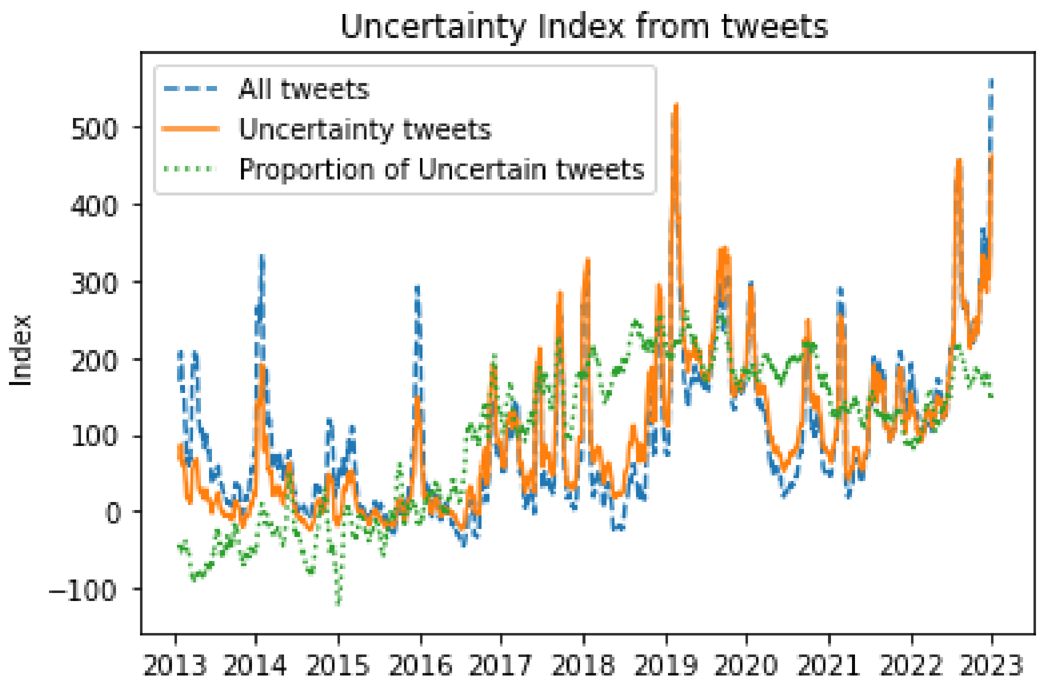
Figure 1. The measure of uncertainty from social media debates



Note: This figure plots the numbers of all tweets, tweets of uncertainty, and the proportion of uncertainty scaled by all tweets on the topic of global warming and climate change. We collect tweets that contains both (i) global warming or climate change; and (ii) uncertainty keywords. All three series were normalised to have a mean value of 100. The blue dashed line represents all tweets on the topic global warming and climate change while the orange solid line shows tweets with uncertainty keyword(s). The green dotted line represents the proportion of uncertainty tweets scaled by all tweets on the topic.

Table 1: Summary statistics

	Green bonds				Ordinary bonds			
	Mean	Std. Dev.	Q1	Q3	Mean	Std. Dev.	Q1	Q3
Yield to Maturity (%)	2.21	2.12	0.49	3.53	3.49	1.95	2.06	4.58
Greenium (%)	0.30	1.82	-0.31	0.91				
Green Uncertainty Index	139.70	82.83	83.15	172.36				
Proportion of Uncertainty tweets (%)	6.78	1.58	4.46	8.22				
Bond Size (log)	18.96	1.58	17.79	20.09	19.28	2.02	18.86	20.50
Maturity (years)	9.35	8.16	5.00	10.00	12.35	9.48	6.00	15.00
Credit rating (CC/D : 1 – AAA : 21)	8.16	7.12	1.00	15.00	13.63	3.81	12.00	16.50
Policy interest rate (%)	0.28	0.70	0.00	0.12	0.64	0.96	0.05	1.12
Inflation rate (%)	2.98	2.11	1.50	4.49	2.85	2.02	1.33	4.49
Observations	2,069				25,026			

This table reports the summary statistics for variables included in the empirical investigations. Our sample includes all green (and non-green for matching purposes) corporate bonds from Bloomberg from 1 January 2013 to 31 December 2022. Greenium is the difference in yield-to-maturity between green versus matching non-green bonds. Green Uncertainty Index is our proposed measure of ex ante uncertainty in social media debates on global warming related topics. We derive this index from almost 7 million Twitter posts.

Table 2: Does Greenium exist ?

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity	(4) Yield to Maturity
Green	-0.1707***	-0.3125***	-0.3164***	-0.2304***
	(-26.61)	(-39.46)	(-39.70)	(-32.06)
Bond Size		0.0595***	0.0627***	0.1014***
		(13.41)	(13.98)	(25.86)
Maturity		0.2199***	-0.0940***	-0.2296***
		(39.34)	(-2.89)	(-6.07)
Credit rating		-0.5029***	-0.6065***	-0.6220***
		(-69.14)	(-43.47)	(-42.69)
Inflation rate		0.1356***	0.1379***	0.0215**
		(25.23)	(25.44)	(2.04)
Policy interest rate		0.4231***	0.4261***	0.2939***
		(86.33)	(87.55)	(49.17)
Credit rating x Maturity			0.3544***	0.4072***
			(9.55)	(9.85)
Constant	***	***	***	***
	(282.51)	(34.54)	(33.91)	(46.70)
Observations	27095	19999	19999	19999
R-squared	0.029	0.469	0.476	0.639

This table reports regressions of yield-to-maturity by a green-bond dummy and other bond characteristics. The dependent variable is bond yield-to-maturity. The main independent variable is the green-bond dummy. In addition, Model (2) controls for the logarithm of bond size; maturity; average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between average rating and maturity. Model (4) adds dummies for issued market, issued year, and industry. The t-statistics based on Huber-White robust standard errors are reported in parentheses.

Table 3: Does Greenium interact with the Green Uncertainty Index ?

	(1)	(2)	(3)	(4)
	Yield to Maturity	Yield to Maturity	Yield to Maturity	Yield to Maturity
High Uncertainty x Green	0.0457***	0.0381***	0.0393***	0.0515***
	(6.19)	(4.59)	(4.64)	(6.89)
Green	-0.1915***	-0.3311***	-0.3356***	-0.2550***
	(-27.09)	(-35.72)	(-35.97)	(-30.93)
Bond Size		0.0582***	0.0613***	0.0991***
		(13.10)	(13.67)	(25.53)
Maturity		0.2199***	-0.0956***	-0.2315***
		(39.35)	(-2.95)	(-6.17)
Credit rating		-0.5051***	-0.6094***	-0.6250***
		(-69.38)	(-43.76)	(-43.09)
Inflation rate		0.1364***	0.1388***	0.0258**
		(25.42)	(25.63)	(2.41)
Policy interest rate		0.4194***	0.4223***	0.2910***
		(86.78)	(88.01)	(49.32)
Credit rating x Maturity			0.3562***	0.4090***
			(9.64)	(9.97)
Constant	***	***	***	***
	(282.50)	(34.83)	(34.25)	(47.38)
Observations	27095	19999	19999	19999
R-squared	0.031	0.470	0.477	0.641

This table reports regressions of yield-to-maturity by a green-bond dummy and other bond characteristics. The dependent variable is bond yield-to-maturity. Main independent variables are the green-bond dummy and the interaction term with a high uncertainty index. In addition, Model (2) controls for the logarithm of bond size; maturity; the average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between average rating and maturity. Model (4) adds dummies for issued market, issued year, and industry. T-statistics based on Huber-White robust standard errors are reported in parentheses.

Table 4: Are green-bond yields sensitive to the Green Uncertainty Index ?

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity	(4) Yield to Maturity
Green Uncertainty Index	0.0959***	0.1139***	0.1140***	0.0434**
	(4.28)	(6.12)	(6.11)	(2.38)
Bond Size		0.0961***	0.0958***	0.1342***
		(2.96)	(2.96)	(5.39)
Maturity		0.1202***	0.0912***	0.0038
		(7.81)	(3.33)	(0.15)
Credit rating		-0.1364***	-0.1663***	-0.2447***
		(-5.07)	(-4.27)	(-7.29)
Inflation rate		0.1640***	0.1644***	-0.0124
		(7.89)	(7.89)	(-0.41)
Policy interest rate		0.5243***	0.5232***	0.2847***
		(23.89)	(23.71)	(13.17)
Credit rating x Maturity			0.0502	0.0771***
			(1.54)	(2.77)
Constant	***			**
	(20.36)	(-1.03)	(-0.93)	(2.32)
Observations	2069	1773	1773	1773
R-squared	0.009	0.336	0.336	0.536

This table reports regressions of the green-bond yield-to-maturity by uncertainty from tweets and other bond characteristics. The dependent variable is the green-bond yield-to-maturity. The main independent variable is measure of uncertainty from social media debates on global warming and climate change. In addition, Model (2) controls for the logarithm of bond size; maturity; average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between average rating and maturity. Model (4) adds dummies for the issued market, issued year, and industry. T-statistics based on Huber-White robust standard errors are reported in parentheses.

Table 5: Event study of green bonds' yields in high (low) uncertainty regimes

Panel A: Green bond Yield-to-Maturity High vs Normal Green Uncertainty Index			
	(1)	(2)	(3)
	High-Uncertainty	Normal	Diff
Yield-to-Maturity	2.758***	2.049***	-0.709***
	(26.96)	(39.66)	(-6.37)
N	456	1613	2069
Panel B: Green bond Yield-to-Maturity Low vs Normal Green Uncertainty Index			
	(1)	(2)	(3)
	Low-Uncertainty	Normal	Diff
Yield-to-Maturity	2.269***	2.197***	-0.0717
	(19.95)	(43.36)	(-0.50)
N	251	1818	2069
Panel C: Greenium High vs Normal Green Uncertainty Index			
	(1)	(2)	(3)
	High-Uncertainty	Normal	Diff
Greenium	-0.292***	0.462***	0.754***
	(-4.69)	(8.50)	(6.82)
N	333	1264	1597
Panel D: Greenium Low vs Normal Green Uncertainty			
	(1)	(2)	(3)
	Low-Uncertainty	Normal	Diff
Greenium	0.577***	0.271***	-0.306*
	(5.91)	(5.46)	(-2.10)
N	175	1422	1597

This table reports a t-test of yield-to-maturity and greenium in high (low) uncertainty regimes. T-statistics are reported in parentheses. Greenium is the difference of yield-to-maturity between a green bond and matching non-green bonds. We match a green bond to non-green bonds with (i) comparable credit worthiness; (ii) comparable maturity; (iii) issued within a month; (iv) same issued currency; (v) same industry short code. Low (High) Green Uncertainty is a dummy variable taking 1 if the number of Green Uncertain tweets is smaller (larger) than the first (third) quartile in its empirical distribution.

Table 6: Consistent effects of uncertainty from social media debates

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity
Green Uncertainty index1w	0.0657***		
	(3.27)		
Green Uncertainty index4w		0.0434**	
		(2.38)	
Green Uncertainty index10w			0.0952***
			(3.89)
Credit rating x Maturity	0.0830***	0.0771***	0.0772***
	(3.01)	(2.77)	(2.79)
Bond Size	0.1336***	0.1342***	0.1328***
	(5.40)	(5.39)	(5.38)
Maturity	0.0029	0.0038	0.0041
	(0.11)	(0.15)	(0.16)
Credit rating	-0.2482***	-0.2447***	-0.2438***
	(-7.40)	(-7.29)	(-7.32)
Inflation rate	-0.0087	-0.0124	-0.0064
	(-0.28)	(-0.41)	(-0.21)
Policy interest rate	0.2778***	0.2847***	0.2631***
	(12.25)	(13.17)	(11.23)
Constant	**	**	**
	(2.32)	(2.32)	(2.39)
Observations	1773	1773	1773
R-squared	0.538	0.536	0.539

This table reports regressions of the green-bond yield-to-maturity by uncertainty from tweets and other bond characteristics. The dependent variable is the green-bond yield-to-maturity. The main independent variable is uncertainty from social media debates on global warming and climate change during 1-week, 4-week, 10-week periods prior to the bond-issued date in Columns (1), (2), and (3), respectively. Control variables include the logarithm of bond size; maturity; average credit ratings from Fitch, Moody's, and S&P's; the interaction term between average rating and maturity; macroeconomic variables; and dummies for issued market, issued year, and industry. T-statistics based on Huber-White robust standard errors are reported in parentheses.

Table 7: Greenium and uncertainty from social media debates

	(1) Greenium	(2) Greenium	(3) Greenium	(4) Greenium
Green Uncertainty index	-0.1422***	-0.1317***	-0.1318***	-0.1144***
	(-7.41)	(-6.79)	(-6.79)	(-4.61)
Bond Size		-0.0924***	-0.0967***	-0.0841***
		(-3.79)	(-3.55)	(-2.81)
Credit rating x Maturity			0.0102	0.0662***
			(0.51)	(2.76)
Constant	***	***	***	***
	(9.08)	(5.08)	(4.86)	(3.86)
Observations	1597	1597	1597	1597
R-squared	0.020	0.029	0.029	0.117

This table reports regressions of green bond premiums; i.e., greenium by uncertainty from tweets and other bond characteristics. The dependent variable is the yield-to-maturity difference between a green bond and a matched-non-green bond. We match a green bond to non-green bonds with (i) comparable credit worthiness; (ii) comparable maturity; (iii) issued within a month; (iv) same currency. The main independent variable is uncertainty from social media debates on global warming and climate change. In addition, Model (2) controls for the logarithm of bond size; maturity; average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between average rating and maturity. Model (4) adds dummies for the issued market, issued year, and industry. T-statistics based on Huber-White robust standard errors are reported in parentheses.

Table 8: Do both social media and the US press have effects on Greenium?

	(1)	(2)	(3)	(4)
	Yield to Maturity	Yield to Maturity	Yield to Maturity	Yield to Maturity
High Uncertainty x Green	0.0461***	0.0414***	0.0426***	0.0518***
	(6.24)	(5.04)	(5.08)	(6.93)
Green	-0.1908***	-0.3240***	-0.3284***	-0.2547***
	(-26.95)	(-35.17)	(-35.39)	(-30.89)
US media	-0.0118**	-0.1130***	-0.1141***	-0.0196***
	(-1.96)	(-20.70)	(-21.00)	(-3.92)
Bond Size		0.0614***	0.0646***	0.0999***
		(14.03)	(14.61)	(25.71)
Maturity		0.2117***	-0.1090***	-0.2309***
		(39.11)	(-3.27)	(-6.14)
Credit rating		-0.5054***	-0.6114***	-0.6246***
		(-69.84)	(-43.52)	(-43.02)
Inflation rate		0.1664***	0.1691***	0.0256**
		(30.16)	(30.34)	(2.39)
Policy interest rate		0.4314***	0.4345***	0.2943***
		(87.53)	(88.77)	(49.36)
Credit rating x Maturity			0.3621***	0.4086***
			(9.60)	(9.94)
Constant	***	***	***	***
	(128.95)	(37.92)	(36.64)	(47.40)
Observations	27095	19999	19999	19999
R-squared	0.031	0.481	0.488	0.641

This table reports the regressions of yield-to-maturity by a green-bond dummy and other bond characteristics. The dependent variable is the bond yield-to-maturity. The main independent variables are the green-bond dummy and the interaction term with the high uncertainty index. US media is the index of climate change concerns the US press introduced in Ardia et al. (2023). In addition, Model (2) controls for the logarithm of bond size; maturity; the average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between the average rating and maturity. Model (4) adds dummies for the issued market, issued year, and industry. T-statistics based on Huber-White robust standard errors are reported in parentheses.

Table 9: Consistent effects of uncertainty from social media debates after controlling for traditional media attention

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity
Green Uncertainty index prior1w	0.0670***		
	(3.20)		
Green Uncertainty index prior4w		0.0425**	
		(2.33)	
Green Uncertainty index prior10w			0.0954***
			(3.91)
US media	-0.0047	0.0048	-0.0010
	(-0.28)	(0.30)	(-0.06)
Credit rating x Maturity	0.0829***	0.0773***	0.0771***
	(3.01)	(2.78)	(2.79)
Bond Size	0.1342***	0.1335***	0.1329***
	(5.34)	(5.31)	(5.32)
Maturity	0.0031	0.0036	0.0041
	(0.12)	(0.14)	(0.16)
Credit rating	-0.2484***	-0.2445***	-0.2438***
	(-7.38)	(-7.27)	(-7.30)
Inflation rate	-0.0083	-0.0128	-0.0063
	(-0.27)	(-0.42)	(-0.21)
Policy interest rate	0.2779***	0.2844***	0.2631***
	(12.28)	(13.15)	(11.23)
Constant	**	**	**
	(2.31)	(2.32)	(2.38)
Observations	1773	1773	1773
R-squared	0.538	0.536	0.539

This table reports regressions of the green-bond yield-to-maturity by uncertainty from tweets and other bond characteristics. The dependent variable is the green-bond yield-to-maturity. The main independent variable is uncertainty from social media debates on global warming and climate change during 1-week, 4-week, 10-week periods prior to bond-issued date in columns (1), (2), (3), respectively. US media is the index of climate change concerns from US press media introduced in Ardia et al. (2023). Control variables include logarithm of bond size, maturity, average credit ratings from Fitch, Moody's, and S&P's, interaction term between average rating and maturity, macroeconomic variables, dummies for issued market, issued year, industry. T-statistics based on Huber-White robust standard errors are reported in parentheses.

Appendices

Appendix A. Proof of Proposition 1

Investors' beliefs after n number of interactions

$$G_t = [\prod_{s=1}^{n} \Theta_s] G_0 \tag{1}$$

According to **Perron–Frobenius Theorem**, as long as Θ_s is the transition matrix of a finite, irreducible, and aperiodic Markov chain $\forall s$, then (i) there is an unique steady state vector w, which spans the 1-eigenspace; (ii) G_∞ approaches wG where $G = \sum_{i=1}^{m} g_0^i$

$$G_\infty = wG \tag{2}$$

Appendix B. Extra empirical results

Table B1: Stricter criteria for matching green-to-ordinary bonds

	(1) Greenium	(2) Greenium	(3) Greenium	(4) Greenium
Green Uncertainty index	-0.1217***	-0.1238***	-0.1238***	-0.1233***
	(-3.27)	(-3.32)	(-3.32)	(-2.89)
Bond Size		0.0791**	0.0789**	0.0511
		(2.11)	(2.08)	(1.19)
Credit rating x Maturity			-0.0039	-0.0121
			(-0.10)	(-0.32)
Constant	***	*	*	
	(2.79)	(-1.89)	(-1.83)	(-0.71)
Observations	607	607	607	607
R-squared	0.015	0.021	0.021	0.113

This table reports regressions of green bond premiums (i.e., greenium by uncertainty from tweets and other bond characteristics). The dependent variable is greenium (i.e., the yield-to-maturity difference between a green bond and a matched-non-green bond). We match a green-bond to non-green bonds with (i) the same creditworthiness (i.e., less than 1-notch difference to credit ratings by Fitch, Moody's, S&P's); (ii) the same maturity (i.e. a less than 1-year difference in year-to-maturity); (iii) issued within a month; (iv) the same issued currency; and (v) the same industry short code.

Table B2: Stricter criteria for matching green-to-ordinary bonds

	(1) Greenium	(2) Greenium	(3) Greenium	(4) Greenium
Green Uncertainty index	-0.1018***	-0.0929***	-0.0903***	-0.0810***
	(-4.60)	(-4.20)	(-4.06)	(-2.82)
Bond Size		-0.1808***	-0.1774***	-0.2054***
		(-2.60)	(-2.60)	(-2.75)
Credit rating x Maturity			-0.0537*	-0.0632**
			(-1.65)	(-2.11)
Constant	***	***	***	***
	(4.27)	(2.70)	(2.72)	(2.70)
Observations	907	907	907	907
R-squared	0.010	0.043	0.046	0.095

This table reports regressions for green bond premiums (i.e., greenium by uncertainty from tweets and other bond characteristics). The dependent variable is greenium (i.e., the yield-to-maturity difference between a green bond and matched-non-green bond.) We match a green-bond to non-green bonds with (i) comparable creditworthiness (i.e., less than a 2-notch difference to credit ratings by Fitch, Moody's, S&P's); (ii) the same maturity (i.e., a less than 2-year difference in year-to-maturity); (iii) issued within a week; (iv) the same issued currency; (v) the same industry short code.

Table B3: Does Greenium exist after controlling for traditional media attention?

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity	(4) Yield to Maturity
Green	-0.1699***	-0.3039***	-0.3077***	-0.2300***
	(-26.41)	(-38.56)	(-38.77)	(-32.00)
US media	-0.0106*	-0.1120***	-0.1130***	-0.0188***
	(-1.76)	(-20.51)	(-20.80)	(-3.76)
Bond Size		0.0628***	0.0660***	0.1021***
		(14.36)	(14.94)	(26.04)
Maturity		0.2118***	-0.1071***	-0.2291***
		(39.09)	(-3.19)	(-6.04)
Credit rating		-0.5030***	-0.6083***	-0.6216***
		(-69.53)	(-43.17)	(-42.62)
Inflation rate		0.1652***	0.1679***	0.0213**
		(29.88)	(30.06)	(2.02)
Policy interest rate		0.4352***	0.4384***	0.2972***
		(87.09)	(88.34)	(49.23)
Credit rating x Maturity			0.3600***	0.4068***
			(9.50)	(9.82)
Constant	***	***	***	***
	(128.72)	(37.53)	(36.19)	(46.69)
Observations	27095	19999	19999	19999
R-squared	0.029	0.480	0.487	0.639

This table reports regressions of the yield-to-maturity by the green-bond dummy and other bond characteristics. The dependent variable is the bond yield-to-maturity. The main independent variable is the green-bond dummy. The US media is the index of climate change concerns from the US press introduced in Ardia et al. (2023). In addition, Model (2) controls for the logarithm of the bond size; maturity, the average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between the average rating and maturity. Model (4) adds dummies for the issued market, issued year, and industry. T-statistics based on Huber-White robust standard errors are reported in parentheses.

Table B4: Are green-bond yields sensitive to the Green Uncertainty Index after controlling for traditional media attention?

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity	(4) Yield to Maturity
Green Uncertainty index	0.0974*** (4.26)	0.1041*** (-5.52)	0.1044*** (-5.51)	0.0425** (2.33)
US media	-0.0066 (-0.28)	-0.0436** (-2.40)	-0.0431** (-2.38)	0.0048 (0.30)
Bond Size		0.1003*** (3.10)	0.1000*** (3.09)	0.1335*** (5.31)
Maturity		0.1197*** (7.86)	0.0918*** (3.39)	0.0036 (0.14)
Credit rating		-0.1409*** (-5.22)	-0.1698*** (-4.36)	-0.2445*** (-7.27)
Inflation rate		0.1708*** (8.19)	0.1711*** (8.18)	-0.0128 (-0.42)
Policy interest rate		0.5232*** (23.92)	0.5221*** (23.74)	0.2844*** (13.15)
Credit rating x Maturity			0.0485 (1.50)	0.0773*** (2.78)
Constant	*** (14.36)	(-0.95)	(-0.86)	** (2.32)
Observations	2069	1773	1773	1773
R-squared	0.009	0.337	0.338	0.536

This table reports regressions of the green-bond yield-to-maturity by uncertainty from tweets and other bond characteristics. The dependent variable is green-bond yield-to-maturity. The main independent variable is the measure of uncertainty from social media debates on global warming and climate change. The US media is the index of climate change concerns from the US press introduced in Ardia et al. (2023). In addition, Model (2) controls for the logarithm of bond size; maturity; the average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between the average rating and maturity. Model (4) adds dummies for the issued market, issued year, and industry. T-statistics based on Huber-White robust standard errors are reported in parentheses.

Table B5: Greenium and uncertainty from social media debates after controlling for traditional media attentions

	(1) Greenium	(2) Greenium	(3) Greenium	(4) Greenium
Green Uncertainty index4w	-0.1348***	-0.1261***	-0.1262***	-0.1107***
	(-6.70)	(-6.23)	(-6.25)	(-4.47)
US media	0.0343	0.0275	-0.0270	-0.0176
	(1.25)	(1.00)	(-0.99)	(-0.64)
Bond Size		-0.0904***	-0.0940***	-0.0828***
		(-3.70)	(-3.44)	(-2.76)
Credit rating x Maturity			0.0083	0.0654***
			(0.42)	(2.74)
Constant	***	***	***	***
	(7.08)	(5.15)	(4.91)	(3.88)
Observations	1597	1597	1597	1597
R-squared	0.021	0.029	0.029	0.117

This table reports regressions of green bond premiums (i.e., greenium by uncertainty from tweets and other bond characteristics). The dependent variable is the yield-to-maturity difference between a green bond and a matched-non-green bond. We match a green bond to non-green bonds with (i) comparable credit worthiness; (ii) comparable maturity; (iii) issued within a month; (iv) the same currency; (v) the same industry. The main independent variable is uncertainty from social media debates on global warming and climate change. The US media is the index of climate change concerns from the US press introduced in Ardia et al. (2023). In addition, Model (2) controls for the logarithm of bond size; maturity; average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between the average rating and maturity. Model (4) adds dummies for the issued market, issued year, and industry. T-statistics based on Huber-White robust standard errors are reported in parentheses.

Table B6: Robustness checks dropping Tesla and its subsidiaries

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity	(4) Yield to Maturity
Panel A: Does Greenium exist ?				
Green	-0.1784***	-0.3143***	-0.3189***	-0.2304***
	(-28.10)	(-39.72)	(-40.04)	(-31.72)
Control variables	No	Yes	Yes	Yes
Observations	27045	19963	19963	19963
R-squared	0.032	0.470	0.477	0.638
Panel B: Does Greenium interact with the Green Uncertainty Index ?				
High Uncertainty x Green	0.0521***	0.0419***	0.0435***	0.0529***
	(7.06)	(5.05)	(5.15)	(7.02)
Green	-0.2024***	-0.3348***	-0.3402***	-0.2558***
	(-29.09)	(-36.04)	(-36.41)	(-30.57)
Control variables	No	Yes	Yes	Yes
Observations	27045	19963	19963	19963
R-squared	0.034	0.471	0.479	0.640

This table reports regressions of yield-to-maturity by a green-bond dummy and other bond characteristics. The dependent variable is bond yield-to-maturity. In Panel A, the main independent variable is the green-bond dummy while it is the interaction term with a high uncertainty index in Panel B. In addition, Model (2) controls for the logarithm of bond size; maturity; average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between average rating and maturity. Model (4) adds dummies for issued market, issued year, and industry. The t-statistics based on Huber-White robust standard errors are reported in parentheses. These are replications of Tables 2 and 3 in the main text without bonds issued by Tesla and its subsidiaries.

Table B7: Robustness checks dropping bonds issued in non-English-speaking markets

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity	(4) Yield to Maturity
Panel A: Does Greenium exist ?				
Green	-0.0174**	-0.1147***	-0.1146***	-0.1092***
	(-2.21)	(-12.24)	(-12.24)	(-11.27)
Control variables	No	Yes	Yes	Yes
Observations	20283	13781	13781	13781
R-squared	0.000	0.471	0.488	0.584
Panel B: Does Greenium interact with the Green Uncertainty Index ?				
High Uncertainty x Green	0.0423***	0.0173	0.0193*	0.0221**
	(5.09)	(1.61)	(1.80)	(1.99)
Green	-0.0367***	-0.1231***	-0.1240***	-0.1200***
	(-4.12)	(-11.18)	(-11.28)	(-10.54)
Control variables	No	Yes	Yes	Yes
Observations	20283	13781	13781	13781
R-squared	0.002	0.471	0.489	0.585

This table reports regressions of yield-to-maturity by a green-bond dummy and other bond characteristics. The dependent variable is bond yield-to-maturity. In Panel A, the main independent variable is the green-bond dummy while it is the interaction term with a high uncertainty index in Panel B. In addition, Model (2) controls for the logarithm of bond size; maturity; average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between average rating and maturity. Model (4) adds dummies for issued market, issued year, and industry. The t-statistics based on Huber-White robust standard errors are reported in parentheses. These are replications of Tables 2 and 3 in the main text without bonds issued in non-English-speaking currencies i.e. Euro, Swiss Franc, Japanese Yen.

Table B8: Robustness checks dropping bonds issued in Japanese Yen

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity	(4) Yield to Maturity
Panel A: Does Greenium exist ?				
Green	-0.1460***	-0.2636***	-0.2664***	-0.2014***
	(-21.43)	(-32.52)	(-32.69)	(-26.53)
Control variables	No	Yes	Yes	Yes
Observations	25952	18986	18986	18986
R-squared	0.021	0.454	0.462	0.611
Panel B: Does Greenium interact with the Green Uncertainty Index ?				
High Uncertainty x Green	0.0582***	0.0634***	0.0667***	0.0764***
	(7.71)	(7.85)	(8.23)	(9.85)
Green	-0.1719***	-0.2939***	-0.2983***	-0.2377***
	(-22.91)	(-30.43)	(-30.64)	(-26.65)
Control variables	No	Yes	Yes	Yes
Observations	25952	18986	18986	18986
R-squared	0.024	0.457	0.466	0.615

This table reports regressions of yield-to-maturity by a green-bond dummy and other bond characteristics. The dependent variable is bond yield-to-maturity. In Panel A, the main independent variable is the green-bond dummy while it is the interaction term with a high uncertainty index in Panel B. In addition, Model (2) controls for the logarithm of bond size; maturity; average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between average rating and maturity. Model (4) adds dummies for issued market, issued year, and industry. The t-statistics based on Huber-White robust standard errors are reported in parentheses. These are replications of Tables 2 and 3 in the main text without bonds issued in Japanese Yen.

Table B9: Robustness checks - Does Greenium exist ?

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity	(4) Yield to Maturity	(5) Yield to Maturity
Green	-0.1707***	-0.3125***	-0.3164***	-0.2304***	-0.0261***
	(-26.61)	(-39.46)	(-39.70)	(-32.06)	(-4.94)
Bond Size		0.0595***	0.0627***	0.1014***	0.0397***
		(13.41)	(13.98)	(25.86)	(7.35)
Maturity		0.2199***	-0.0940***	-0.2296***	0.1771***
		(39.34)	(-2.89)	(-6.07)	(8.27)
Credit rating		-0.5029***	-0.6065***	-0.6220***	-0.0455***
		(-69.14)	(-43.47)	(-42.69)	(-3.19)
Inflation rate		0.1356***	0.1379***	0.0215**	0.0063
		(25.23)	(25.44)	(2.04)	(0.87)
Policy interest rate		0.4231***	0.4261***	0.2939***	0.3081***
		(86.33)	(87.55)	(49.17)	(63.98)
Credit rating x Maturity			0.3544***	0.4072***	0.0332
			(9.55)	(9.85)	(1.44)
Constant	***	***	***	***	***
	(282.51)	(34.54)	(33.91)	(46.70)	(14.47)
Observations	27095	19999	19999	19999	19986
R-squared	0.029	0.469	0.476	0.639	0.903

This table reports regressions of yield-to-maturity by a green-bond dummy and other bond characteristics. The dependent variable is bond yield-to-maturity. The main independent variable is the green-bond dummy. In addition, Model (2) controls for the logarithm of bond size; maturity; average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between average rating and maturity. Model (4) adds dummies for issued market, issued year, and industry. Model (5) adds issuer effects. The t-statistics based on Huber-White robust standard errors are reported in parentheses.

Table B10: Robustness checks - Does Greenium interact with the Green Uncertainty Index ?

	(1) Yield to Maturity	(2) Yield to Maturity	(3) Yield to Maturity	(4) Yield to Maturity	(5) Yield to Maturity
High Uncertainty x Green	0.0457***	0.0381***	0.0393***	0.0515***	0.0233***
	(6.19)	(4.59)	(4.64)	(6.89)	(5.98)
Green	-0.1915***	-0.3311***	-0.3356***	-0.2550***	-0.0396***
	(-27.09)	(-35.72)	(-35.97)	(-30.93)	(-7.17)
Bond Size		0.0582***	0.0613***	0.0991***	0.0393***
		(13.10)	(13.67)	(25.53)	(7.29)
Maturity		0.2199***	-0.0956***	-0.2315***	0.1745***
		(39.35)	(-2.95)	(-6.17)	(8.19)
Credit rating		-0.5051***	-0.6094***	-0.6250***	-0.0513***
		(-69.38)	(-43.76)	(-43.09)	(-3.65)
Inflation rate		0.1364***	0.1388***	0.0258**	0.0068
		(25.42)	(25.63)	(2.41)	(0.93)
Policy interest rate		0.4194***	0.4223***	0.2910***	0.3070***
		(86.78)	(88.01)	(49.32)	(63.94)
Credit rating x Maturity			0.3562***	0.4090***	0.0358
			(9.64)	(9.97)	(1.55)
Constant	***	***	***	***	***
	(282.50)	(34.83)	(34.25)	(47.38)	(14.71)
Observations	27095	19999	19999	19999	19986
R-squared	0.031	0.470	0.477	0.641	0.904

This table reports regressions of yield-to-maturity by a green-bond dummy and other bond characteristics. The dependent variable is bond yield-to-maturity. Main independent variables are the green-bond dummy and the interaction term with a high uncertainty index. In addition, Model (2) controls for the logarithm of bond size; maturity; the average credit ratings from Fitch, Moody's, and S&P's; and macroeconomic variables. Model (3) adds the interaction term between average rating and maturity. Model (4) adds dummies for issued market, issued year, and industry. Model (5) adds issuer effects. T-statistics based on Huber-White robust standard errors are reported in parentheses.